DESIGN OF MICROSTRIP ANTENNA FOR WIRELESS APPLICATIONS

A thesis submitted in partial fulfillment of the requirements for the degree of

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IN

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By

KIRTI SAI SHUKLA

(Roll No: 111EC0262)

Under the supervision of
Prof. S. K. Behera

Department of Electronics and Communication Engineering
National Institute of Technology
Rourkela
2015

Department of Electronics and Communication Engineering
National Institute of Technology Rourkela-769008

CERTIFICATE

This is to certify that the thesis titled, "**DESIGN OF MICROSTRIP ANTENNA FOR WIRELESS APPLICATIONS**" submitted by **Mr. Kirti Sai Shukla** for partial fulfilment of the requirements for the award of Degree of Bachelor of Technology in **ELECTRONICS AND COMMUNICATION ENGINEERING** at National Institute of Technology Rourkela is an original work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

Date:

Dr. S. K. BEHERA
Associate Professor

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We would like to thank all our friends for helping us and would also like to thank all those who have directly or indirectly contributed to the success of our work.

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KIRTI SAI SHUKLA

ABSTRACT

In this thesis, the focus is not in designing any antenna for a particular wireless application but a study on the existing antennas has been made and the methods by which their performance can be improved. The antennas chosen are the standard designs, ones which are most rampantly used in the wireless applications like the Bluetooth, Wi-Fi & Wireless LAN applications in the frequency range of 2.45GHz. An antenna was also designed taking into consideration the GSM band. The bandwidth of the antenna has been given special attention since data rate criterion have to be met apart from the resonant frequency. A circularly polarised antenna was also designed that could be optimised for GPS applications.

Further in the thesis a Patch antenna calculator has been designed in MATLAB to reduce the repetitive task of finding the antenna dimension for a rectangular microstrip patch. A GUI has been developed using MATLAB GUIDE tool to provide a user-friendly interface. The calculations are done in the background for several antenna parameters using the cavity model for microstrip patch antenna. This GUI would be helpful in getting the basic idea about a few basic antenna parameters before the design, simulation and parametric analysis in software like CST Microwave Studio, HFSS and IE3D.

To miniaturize the antennae further a metamaterial based approach has been incorporated. A comparative analysis of different conventional and metamaterial based microstrip patch antenna. A study of SRR based microstrip antenna and their equivalent circuits have been carried out. A unit cell of SRR has also been designed for the frequency of 10.25 GHz. Using such metamaterial unit cell a miniaturized microstrip patch antenna can be realised as per our requirements.

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Chapter 1

INTRODUCTION AND OVERVIEW

CHAPTER 1

INTRODUCTION AND OVERVIEW

The concept of communication begins from the time when humans felt the requirement to share their thoughts. Man started to use his voice to communicate with others. Languages evolved with time but the medium of communication has been air from time immemorial. But this human voice had its own limitations. It cannot be used over large distances even though you are able to visually locate the receiving person. Then evolved techniques like drums, signal flags etc. which helped in sending a coded message through larger distances. Considering these communications techniques, the used a very narrow bandwidth of the electromagnetic spectrum. Moreover there was very little interference in such techniques as the number of users were far less in number compared what they are today. More recently have we explored that even the frequencies outside the visible range in the electromagnetic spectrum can be used to communicate messages. Thus radio was born which utilised the greatest natural resource in form of radio spectrum for communication. And thus was born the first antenna which has truly helped not only harnessing the resource but also popularising it by leaps and bounds.

1.1. Aim and Objectives

Microstrip patch antennas are small antennas that are fabricated over a Printed Circuit Board and can be used in embedded systems and applications as such. In this thesis, our aim is to provide a solution for the various demanding parameters in the microstrip patch antenna for reduction in size apart from large bandwidth and higher data rates. The objective is to study the different antenna parameters and come up with a comparative study on why metamaterial based antenna are better than the conventional antenna. We have also created an interactive Graphical User Interface (GUI) that would help in calculation of antenna parameters.

1.2. Motivation

Today wireless communication has become more of a dire necessity in various applications. In many scenarios where the wired systems are impractical or almost impossible to be implemented, wireless systems have readily replaced them. Many systems are actually required to actually transmit a message and receive it with minimal error in a wireless systems. Such blocks like transmitter, receiver, coders etc. are required to pass information both over short and long distances.

Now-a-days with the advent of Internet of Things (I.O.T) applications, wireless networking has increased manifold both in terms of number and complexity. Take the example of the unlicensed spectrum of 2.4 GHz for interconnecting Wi-Fi devices such as connecting laptops or mobile devices for people in transit. This spectrum in small range is used for communicating multiple devices in various networks thereby generating requirement of various kinds of specialised antenna for the suitable purpose.

One more use for wireless systems is one that connect the mobile network to connect to the satellites. Take the example of GPS systems where devices need to be within the range of three or more satellites. The location is transmitted from the satellites in range via the communicating channels. So practically the antenna needs to be designed in such a manner that the signals can be detected in any orientation. So a circularly polarised antenna is the requirement for such an application which overcomes the orientation problem.

With embedded systems in use at large, antennas have to be integrated into small, portable systems. Small antenna at a particular resonant frequency can be made feasible with various design techniques in the microstrip patch antenna. Recently with the use of metamaterials and dielectric resonators, the antenna size have been drastically reduced to very small sizes for actual practical applications.

1.3. Antenna and its types

An antenna is a means of radiating and receiving the radio waves. It is a transition structure between the free space and the guiding device. So it can be said as a directional device that guides the device and can also probe for signals. In Figure 1.1 one can easily see the role of antenna in wireless communication

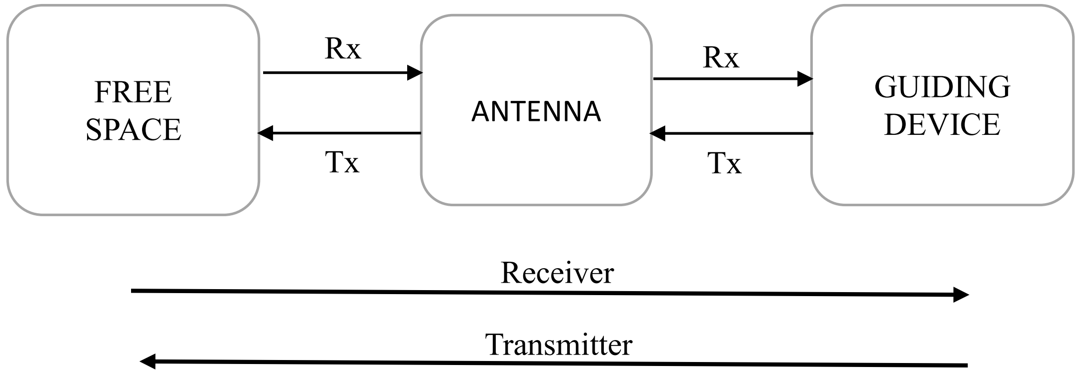


FIGURE 1.1: Basic block diagram depicting the role of antenna in transmission and reception

The equivalent circuit of an antenna is given in Figure 1.2. as one can see that there is an impedance (Zg) at the generator. The characteristic impedance of the transmission line (Zc) which does not depend on the length of the transmission line but depends upon the material used in the transmission line and the impedance matching. The impedance of the antenna (Za) is given by

$$Za = (Rl + Rr) + j\ Xa$$

where

Rl is the conduction and dielectric loss
Rr is the radiation resistance
Xa is the radiation impedance

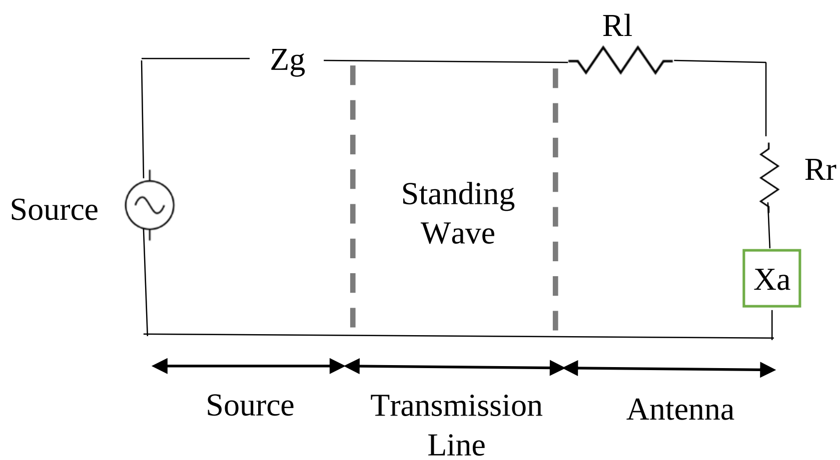


FIGURE 1.2: Equivalent Circuit Diagram of the antenna as a guiding device

There are several ways to classify the antennas. If we classify on basis of frequency band we can have narrowband, wideband and ultra-wideband antennas. The antennas can be considered to be classified on the basis of electromagnetic, physical or electrical structure. Directionality also defines the classification in antenna as they can be directional and non-directional in nature.

There can be different types of antenna. The following chart in Figure 1.2 depicts the different types of antenna and their combinations or derivatives. The main antenna and their types are mentioned herewith. For further details on types of antenna one can refer to [1].

- **Conducting Wire:** They are mainly constituted of a single wire. These are further arranged in form of dipoles, loops and helices'.
- **Apertures:** They consist of a radiating aperture for higher directivity. These are further subdivided to waveguides and horns.
- **Patch (Microstrip):** These are the majorly used in embedded applications. They can be of various shapes like rectangular, circular etc.
- **Array of elements:** they consist of a group of smaller antennas excited at a fixed phase difference to generate high directivity.
- **Reflector**
- **Lens**

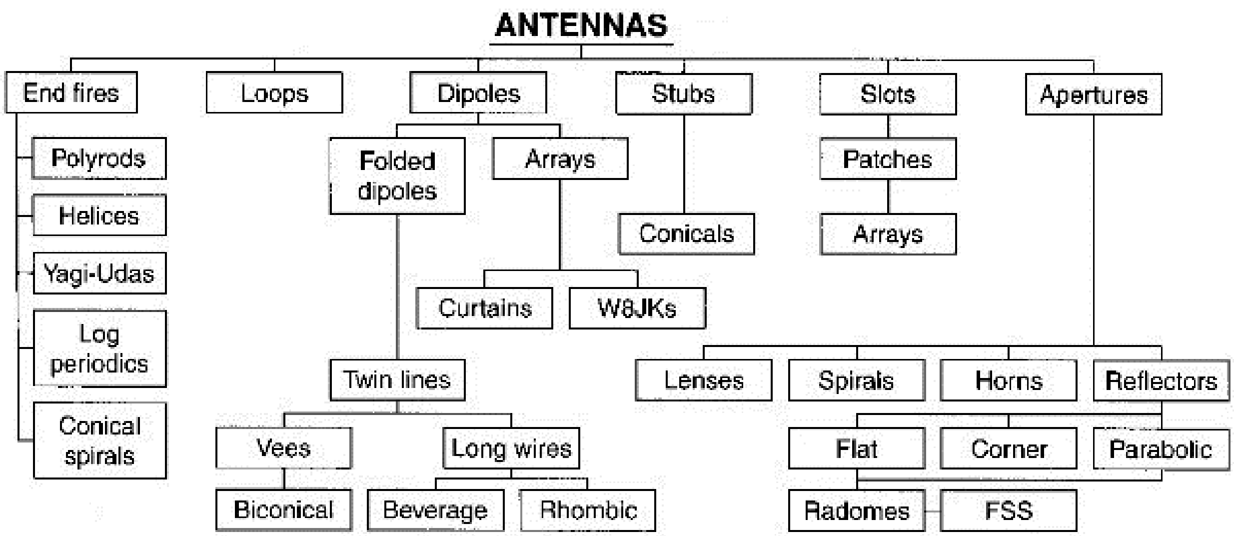


FIGURE 1.3: Classification of antenna on basis of physical structures

1.4. Microstrip Antenna

A microstrip patch antenna consists of a dielectric substrate sandwiched by a radiating patch on one side and the ground plane on the other side as shown in Figure 1.4. The radiating patch is made of a good conductor material such as annealed copper or gold. It can take any shape in the two dimensional plane and thus unlimited configurations are possible. The shapes can be anything ranging from triangular, circular, semi-circular and rectangular. The feed-lines and the radiating patch are usually photo-etched on the dielectric substrate. The dielectric substrate can be thick or thin, and must be chosen with permittivity between 2.2 to 12. The patch thickness should be much less than the operating wavelength of the antenna.

The radiation in microstrip patch antennas is due to the fringing fields between the edge of the patch and the ground plane. A thick substrate with a very low dielectric constant is suitable for good antenna performance since it provides a larger bandwidth, better efficiency and better radiation. But in such a scenario, the antenna size increases. Thus to reduce the size, substrate with high dielectric constants must be used which have narrow bandwidth and are less efficient. Hence a proper trade-off must be done at the designing stage to realise an improved performance of an antenna at a particular operating frequency and constrained physical dimensions. The figure below shows a standard rectangular microstrip patch antenna.

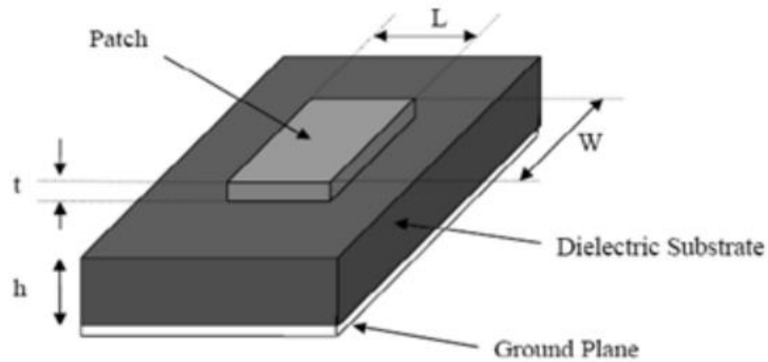


FIGURE 1.4: Rectangular Microstrip Patch Antenna

1.5. Waves in Microstrips

To understand the intricate mechanisms of transmission and radiation in a microstrip patch one needs to consider a current point source i.e. a Hertz Dipole that is located on top of a grounded dielectric substrate as shown in figure 1.5. Such a source can radiate electromagnetic radiations and thus based on the transmitting wave's direction, they fall within three distinct categories, each exhibiting different behaviours.

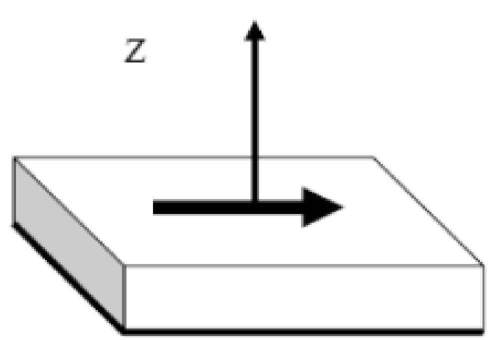


FIGURE 1.5: Hertz Dipole on a Microstrip Antenna

1.5.1. Surface Waves

When the waves are transmitted slightly downward, having elevation angles between pi/2 radians and pi/2 – arc sin (1/√εr), meet the ground planes, it reflects them and then reflects back to meet the dielectric air boundary. This dielectric-to-air boundary also reflects back the wave, ths causing Total Internal Reflection. These waves build up to meet for some particular radiation angles leading to discrete set of surface wave modes. These modes are similar to those found in metallic waveguides.

From the total signal energy, a part of it goes towards surface waves. Thus this energy is wasted and does not reach the user. So it decreases the antenna efficiency due the apparent attenuation and a degradation in the antenna performance is observed.

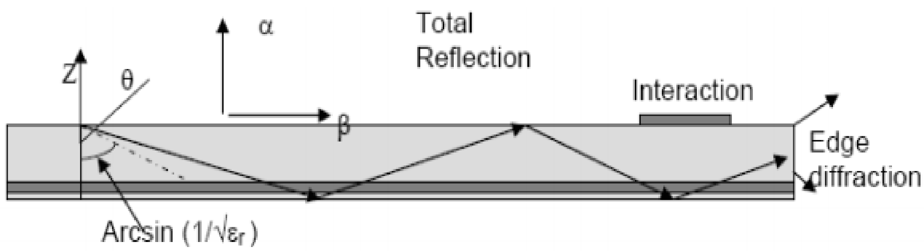


FIGURE 1.6: Surface Wave in Microstrip Patch

1.5.2. Leaky Waves

The waves that are directed more sharply downwards with angles between π - arcsin (1/√εr) and π, get reflected by the ground plane. But the dielectric-to-air boundary can only partially reflect it back and so the waves leak from the surface of the antenna eventually. The field amplitude increases as one moves away from the substrate since wave radiates from a point where the signal amplitude is larger.

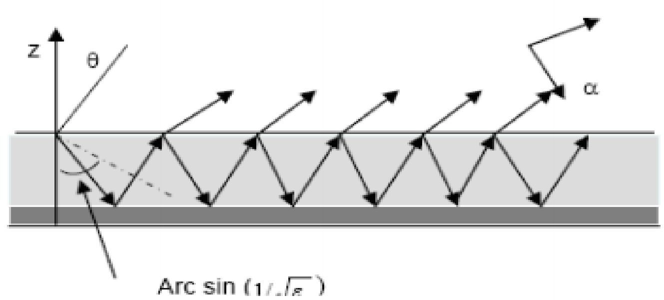


FIGURE 1.7: Leaky Waves on Microstrip Patch

1.5.3. Guided Waves

For feasibly fabricating printed circuit boards for a microstrip patch antenna a metal layer is locally added over the top of the surface that modifies the geometry thereby introducing an additional reflecting boundary. The guided waves have a normal mode of operation in transmission lines and circuits where the electromagnetic field is concentrated in the bulk below the upper conductor. But such a build-up of electromagnetic energy is not favourable for patch antennas that perform like resonators having limited frequency bandwidth.

1.6. Organisation of the Thesis

The first chapter discuses on the introduction of the antenna focusing on the radiation of the microstrip patch antenna.

In the second chapter a brief introduction to microstrip patch antennas is provided. Here in this chapter, various advantages and disadvantages of such antennas have been discussed. Further the various feeding techniques have been discussed. In the end of the chapter, a brief introduction to the various models used for the study of microstrip patch antenna has been provided.

In Chapter 3, a detailed discussion on rectangular microstrip patch antenna has been presented. After introducing the antenna and knowing its basic features more stress has been laid on the antenna parameters. Finally a basic simulation of a rectangular microstrip patch antenna has been simulated and explained in detail using CST Microwave Studio.

Chapter 4 deals with a MATLAB based Graphical User interface (GUI) for calculating the patch antenna parameters. Using a few input values from the user, the outputs are calculated using a standard patch antenna equations using functions in GUIDE, the development environment for User Interface (UI) systems in MATLAB.

Chapter 5 is based on meta-materials, where we get to know about meta-materials. A study on how can they help in improve several antenna parameters has been discussed. A meta-material Split Ring resonator (SRR) structure unit has been designed for a particular frequency. Further a study on the various equivalent circuits of SRR structures having meta-material property has been studied and presented systematically.

In the last chapter we will discuss about the conclusion of the thesis and its future scope for further work in this field.

Chapter 2

MICROSTRIP PATCH ANTENNA

Introduction

Advantages and Disadvantages

Feeding Methods

Analysis Methods

CHAPTER 2

MICROSTRIP PATCH ANTENNA

If you want a light-weight, low cost, conformal antenna, then the microstrip patch antenna are the best for such a requirement. Weather you need to integrate it with strip-line printed networks or be it any active device, microstrip patch antennas are much sought after. The most extensively used microstrip designs are the rectangular and circular patch. The age of miniaturization has brought in several advances in design of conformal microstrip patch antennas. These antennas have recently become very popular due to their various properties that win over other antenna designs overcoming several of its own disadvantages.

2.1. Introduction

A microstrip patch antenna is used for generally narrowband applications. It has a wide-beam which is made by etching the design pattern on the metallic surface over a dielectric insulating base. A continuous metal layer in the opposite side of the strip forms the ground plane. Microstrip patch antennas can be found in many shapes as shown in figure 2.1. Common shapes are regular like square, rectangular, circular, triangular etc. but in fact any irregular but continuous shape is possible. Regular shapes are generally chosen because of ease of analysis, ease of fabrication, attractive radiation characteristics and low cross radiation properties. Instead of dielectric substrate, dielectric spacers are used so that the structure becomes less rugged but a wide bandwidth.

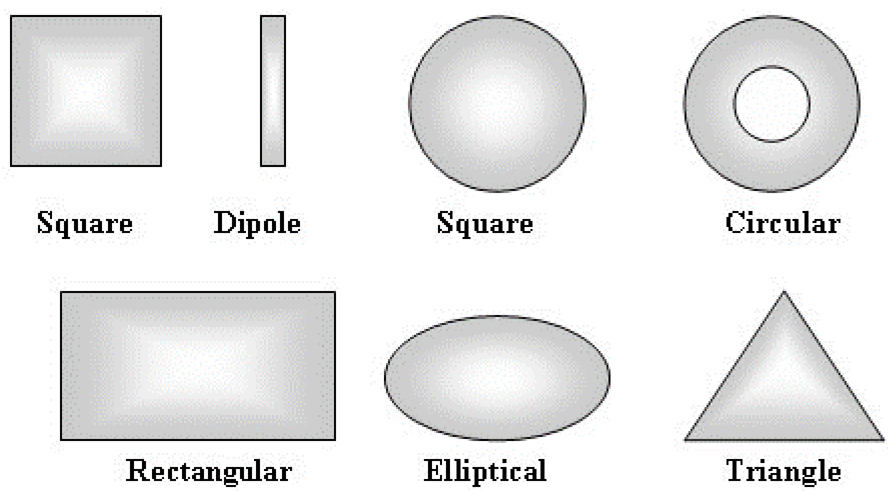


FIGURE 2.1: Different shapes of Microstrip Patch Antenna

2.2. Advantages and Disadvantages

The low-profile nature and its compatibility with embedded systems in wireless devices like mobile phones, PDAs etc. has immensely popularised microstrip patch antennas. In warfare antennas need to be placed over missiles for communication and telemetry. Such antennas need to be thin and conformal which can be only made possible by microstrip patch antenna. Apart from many advantages Microstrip patch antennas suffer from far more drawbacks in comparison to conventional antennas. Some of the advantages and disadvantages are compared in the table below as discussed in detail in [2]:

Sl. No.	Advantages	Disadvantages
1.	Light weight & low volume	Narrow bandwidth.
2.	Low profile planar configuration that can be easily made conformal to host surface	Low efficiency
3.	Low fabrication cost, hence can be manufactured in large quantities.	Low Gain
4.	Supports both, linear as well as circular polarization.	Extraneous radiation from feeds and junctions.
5.	Can be easily integrated with microwave integrated circuits (MICs).	Poor end fire radiator except tapered slot antennas
6.	Capable of dual and triple frequency operations.	Low power handling capacity.
7.	Mechanically robust when mounted on rigid surfaces	Surface wave excitation.

TABLE 2.1: Advantages and Disadvantages of Microstrip Patch Antenna

Microstrip patch antennas suffer an increasing loss in radiated wave with increasing substrate thickness. Substrate is expected to be thick for larger bandwidth. This unwanted surface wave power loss gets scattered and causes degradation of antenna radiation. Some other problems like low power gain and low power handling capacity can be overcome by other methods.

2.3. Feeding Methods

Microstrip patch antennas can be fed using varieties of techniques. The feed-line can be either be in direct contact or without any contact. In direct contact, the power is fed directly to the patch using feed-line made of connecting elements like microstrip line. In indirect contact, a coupling is done between the feed-line and the radiating patch. The most popular feeding techniques used are microstrip line and coaxial probe which come under direct contact schemes and again aperture coupling and proximity coupling that come under indirect contact.

2.3.1. Microstrip Line

Here the conducting strip is attached directly to one edge of the microstrip patch as shown in the figure 2.2. The width of this strip is smaller than the patch and is conducting in nature. Thus it provides a planar structure for feed arrangement. It provides an ease of fabrication and simple modelling. With inset feed precision can be achieved at impedance matching. Here the feed radiation generally leads to spurious radiations

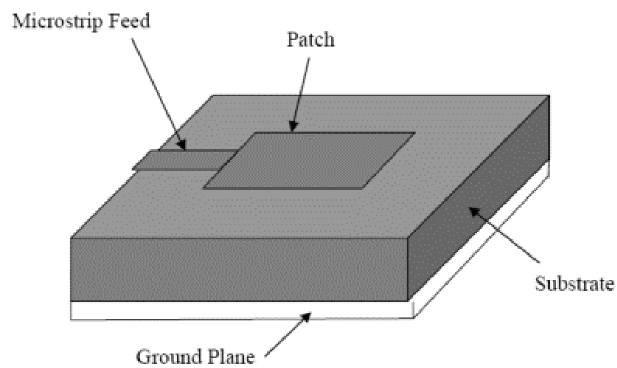


FIGURE 2.2: Microstrip Line Feed

2.3.2. Co-axial Probe

Here, the feed is given via a coaxial cable. The inner conductor extends to the radiating patch through the dielectric and is soldered there. The outer conductor is connected to the ground plane. The most important advantage of this method is that the probe can be placed at any location inside the patch to suit the impedance matching. It is easy to fabricate and has lower spurious radiation. Modelling it is difficult and its narrow bandwidth is generally not desired. Again the input impedance becomes more inductive for thicker substrates leading to matching problems.

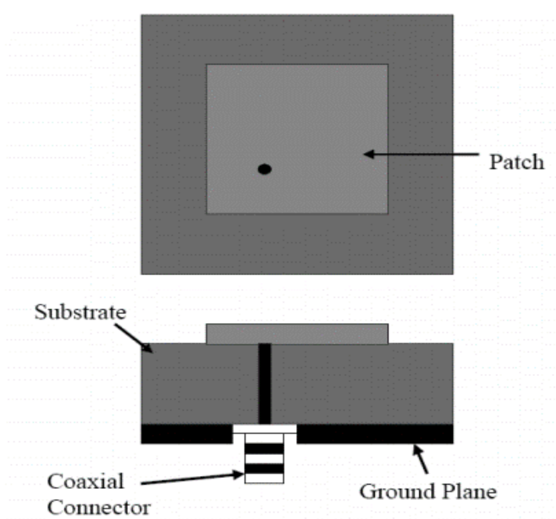


FIGURE 2.3: Co-axial Feed line

2.3.3. Aperture Coupling

Here in aperture coupling, the radiating patch and the feed-line are separated by the ground plane as depicted in the figure. The coupling is made possible through an aperture or slot in the ground plane. This slot is centred around the patch. This leads to lower cross polarization due to configuration symmetry. The shape, size and location of the slot decides the amount of coupling.

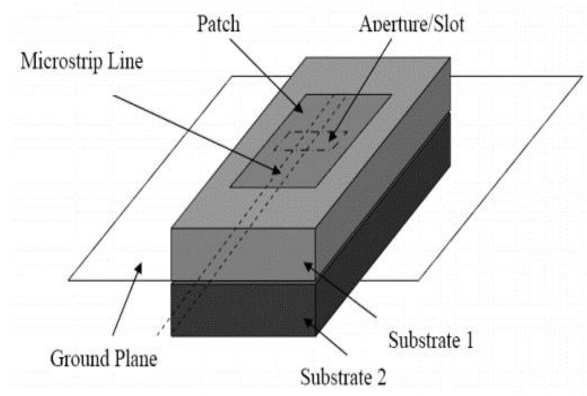


FIGURE 2.4: Aperture Coupling

2.3.4. Proximity Coupling

Proximity Coupling has two dielectric substrates. The feed-line is in between these substrates and the radiating patch is on top of the upper substrate. This technique drastically reduces any kind of spurious radiation feed thereby increasing the bandwidth as there is an overall increase I the substrate thickness. We can also individually choose the different dielectric media for better performance.

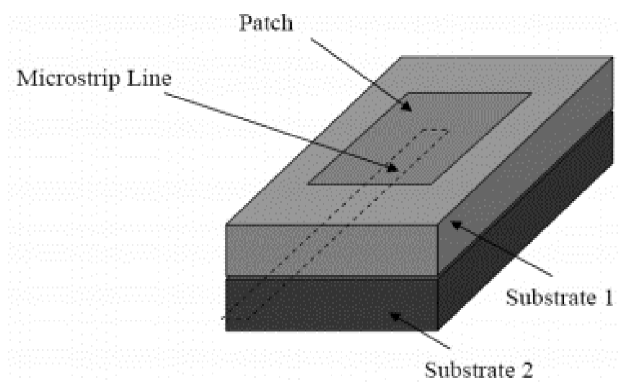


FIGURE 2.5: Proximity Coupling

2.4. Analysis Methods

The two major models used in the study of microstrip patch antennas are the transmission line model and cavity model. Transmission model is the simplest of all. Even though it is a bit less accurate, it gives an approximate physical insight. On the other hand, the Cavity Model is complex in nature. But it gives a very good physical insight and is more accurate. Another model called the Full Wave model which even though gives less insight compared to the above two models and is far more complex gives extremely accurate, versatile and can easily treat single elements, finite and infinite arrays and various other complex shape.

2.4.1. Transmission Line Model

The transmission line model represents the microstrip antenna by two slots each of width (W) and height (h), separated by the transmission line of length (L). Microstrip is generally a non-homogenous line of two dielectrics, generally the substrate and the air as seen in figure 2.6.

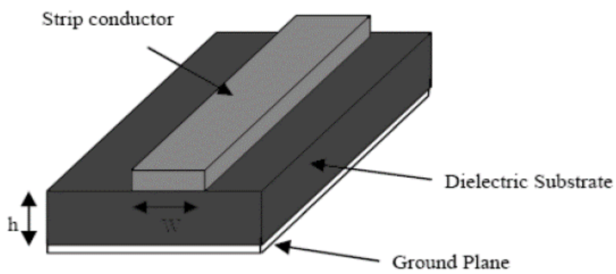


FIGURE 2.6: Microstrip Line

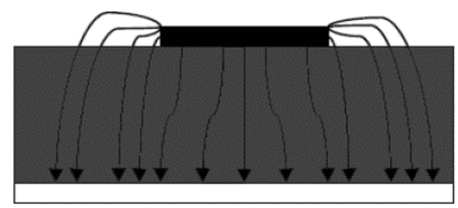


FIGURE 2.7: Electric Field Lines

We can see in figure 2.7 that most of the electric field lines lie inside the substrate and very few of them lie outside in air. Thus pure TEM mode cannot be supported, and instead of that the quasi-TEM mode would be the dominant mode of propagation. So to account for the fringing effects and wave propagation an effective dielectric constant (ε_{reff}) must be obtained. This value will be slightly smaller than the relative permittivity (ε_r) since the fringing fields around the perimeter of the patch are not confined in the substrate but are also spread as shown in the figure 2.7 above. The ε_{reff} equation is stated in [1] as:

If $\frac{w}{h} < 1$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \left(\frac{\varepsilon_r - 1}{2}\right)\left[\frac{1}{\sqrt{\left(1 + \frac{12h}{e}\right)}}\right] + 0.04\left(1 - \frac{w}{h}\right)^2 \quad \text{.................................. (2.1)}$$

If $\frac{w}{h} >= 1$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \left(\frac{\varepsilon_r - 1}{2}\right)\left[\frac{1}{\sqrt{\left(1 + \frac{12h}{e}\right)}}\right] \quad \text{.................................. (2.2)}$$

where, ε_{reff} = Effective Dielectric Constant

ε_r = Dielectric Constant of the Substrate

h = Height of the electric substrate

W = Width of the Patch

It can be seen that we need to operate in TM_{10} mode, and hence the length of the patch must be slightly less than $\lambda/2$ where λ is the wavelength in the dielectric medium and is equal to $\lambda_o/\sqrt{\varepsilon_{reff}}$ where λ_o is the free space wavelength. Also the normal components of the electric field along the two edges of the width are in opposite directions and thus out of phase. On the other hand the tangential components are in phase. It actually means that the resultant fields combine to give maximum radiated field normal to surface of the structure.

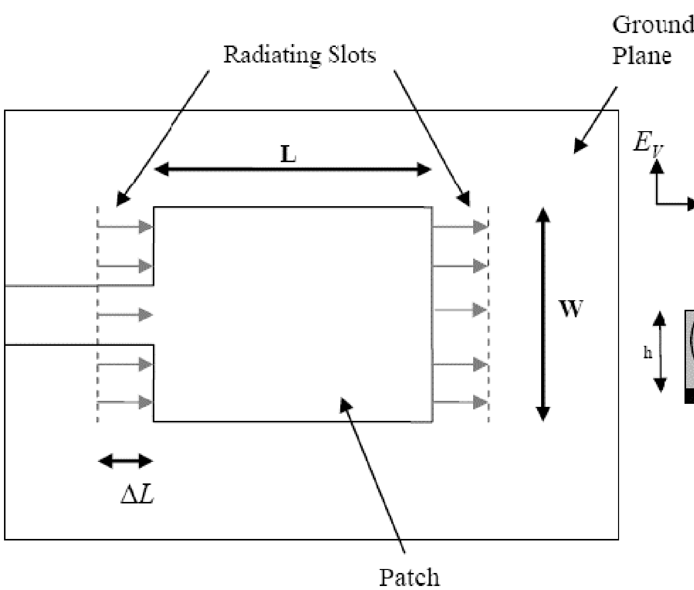


FIGURE 2.8: Top View of Antenna

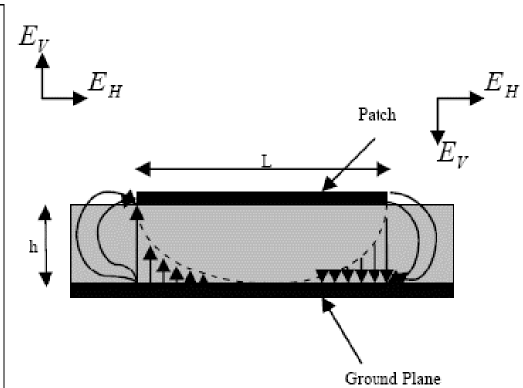


FIGURE 2.9: Side View of Antenna

Hence the fringing fields along the width can be modeled as radiating slots and thus the electrical length of the patch becomes greater than its physical length. So there is an increase in the length of the patch by the factor ΔL defined by [1]:

$$\Delta L = 0.412h \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \qquad \text{.................................. (2.3)}$$

Thus the effective length now becomes: $L_{eff} = L + \Delta L$

Hence for a given frequency f_o, the effective length is given by

$$L_{eff} = \frac{c}{2 f_o \sqrt{\varepsilon_{reff}}} \qquad \text{.................................. (2.4)}$$

For a rectangular Microstrip patch antenna, the resonant frequency for any TM_{010} mode is as defined by

$$f_o = \frac{c}{2\sqrt{\varepsilon_{reff}}}\left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2\right]^{\frac{1}{2}} \qquad \text{.................................. (2.5)}$$

where m and n are modes along L and W respectively
For efficient radiation, the width W is given by [1] as,

$$W = \frac{c}{2 f_o \sqrt{\frac{(\varepsilon_r + 1)}{2}}} \qquad \text{.................................. (2.6)}$$

2.4.2. Cavity Model

The cavity model provides a mathematical solution for the electric and magnetic fields of a microstrip antenna and hence helps to have an insight into the radiation mechanism of the antenna. The solutions are found by representing the antenna using a dielectrically loaded cavity. Although it models the substrate material, but it considers that the material is truncated at the patch edges. Both the patch and ground plane are represented as perfect electric conductors and edges of the substrate are suitably modeled as perfectly conducting magnetic walls. In the figure below one can see the charge distribution as visible not only in the upper and lower surfaces of the patch but also at the bottom of the ground plane. It is controlled by both attractive and repulsive mechanisms by which the charges move in a particular manner causing flow of current at the top and bottom of the patch.

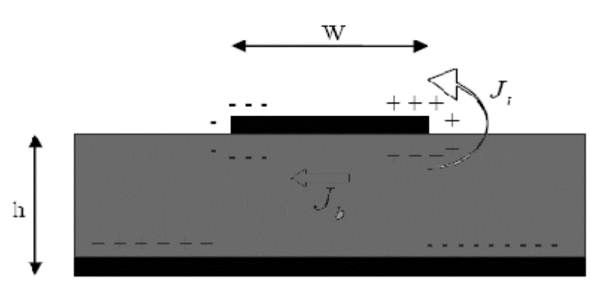


FIGURE 2.10: Charge distribution and current density creation on the microstrip patch

Chapter 3

RECTANGULAR MICROSTRIP PATCH ANTENNA

Introduction

Basic Principles of Operation

Performance Parameters

Simulation of Rectangular Microstrip Patch Antenna

CHAPTER 3

RECTANGULAR MICROSTRIP PATCH ANTENNA

3.1.Introduction

A rectangular patch antenna is the most commonly used microstrip patch antenna. This antenna is approximately a 0.5 wavelength long section for transmission line of rectangular patch. Suppose air is in the antenna substrate, then we can consider the length of the rectangular microstrip antenna to be one-half of the wavelength of the free-space. Once loading of the substrate starts with dielectric, the length of the antenna decreases since there is an increase in the dielectric constant of the substrate. Again due to fringing effects, the resonant length of the antenna is shorter as the electric length would have slightly increased. In earlier models of microstrip patch antennas, equivalent loads are introduced in the ends of the microstrip transmission line to represent the radiation loss.

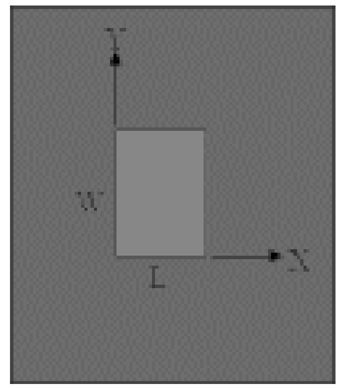


FIGURE 3.1: Rectangular Microstrip Patch Antenna

3.2. Basic Principles of Operation

The rectangular metallic patch with patch on the top, edges on the side and ground on the bottom creates a resonant cavity. The edges of the patch behave like open-circuit boundary condition. Thus the patch acts as a cavity with perfect electric conductor on top and bottom and perfect magnetic conductor in the sides. This is vital in understanding the patch antenna and its behavior.

If the substrate is considered to be electrically thin, it is difficult to assume it to be effective radiator, since the patch current will be effectively shorted owing to its closeness to the ground plane. The strength of the radiated field from the resonant patch is actually independent of height of the substrate h when losses are ignored. Similarly the resonant input resistance will likewise be independent of h. thus a patch antenna can be an effective radiator even for small substrate heights, although the bandwidth is small.

3.3. Performance Parameters

A number of parameters can be taken into consideration while judging the performance of an antenna. The following parameters are the critical ones for microstrip patch antenna..

3.3.1. Radiation Pattern

The radiation pattern is a three dimensional graphical representation of the radiation of the antenna as the function of direction. It is actually the plot of power radiated from an antenna per unit solid angle [1]. If we consider the total power radiated by an isotropic antenna to be P, with a spread over a sphere of radius r then the power density S at this point in any direction is given as:

$$\boldsymbol{S = \frac{P}{4\pi r^2}} \qquad \text{.................................. (3.1)}$$

Isotropic antennas do not exist in reality but are generally used as an reference to compare the performance of other antennas. For an isotropic antenna, the radiation intensity can be calculated as

$$Ui = \frac{P}{4\pi} \qquad \text{.................................. (3.2)}$$

The radiation pattern provides all the required information on antenna beam-width, side-lobes and resolution of the antenna.

3.3.2. Gain

The ratio of the maximum radiation intensity at the peak of the beam to the radiation intensity in the same direction produced by an isotropic radiator having same input power is known as the Gain of the Antenna. The gain of the isotropic radiator is considered to be unity. The gain is defined as in [1]:

$$G(\theta, \emptyset) = \frac{P(\theta,\emptyset)}{\frac{Wt}{4\pi}} \qquad \text{.................................. (3.3)}$$

Where, $P(\theta, \emptyset)$ is defined as the power radiated per unit solid angle in direction $(\theta, \emptyset)$
Wt is the total radiated power

Due to poor radiation efficiency microstrip patch antennas have poor radiation efficiency. Research is being conducted at several levels to obtain high gain antennas.

3.3.3. Directivity

The ratio of normalized power density at the peak of the main beam of the three dimensional antenna pattern to the average power density is known as directivity. The directivity of the antenna is given by:

$$D = \frac{Pmax}{Pav} \qquad \text{.................................. (3.4)}$$

The relation between directivity and gain can be given as:
$G = \eta D$ where η is the antenna efficiency.

3.3.4. Bandwidth

Bandwidth is the range of usable frequencies within which the performance of the antenna with respect to desired character, meets the specific standards. Bandwidth ranges across a central frequency and within this range all the other antenna parameters like radiation pattern, input impedance, beam-width, polarization, gain, directivity are within the tolerable limits from their corresponding values at the central frequency.The bandwidth of narrow band and broadband antennas are defined as [1]:

$$BWbroadband = \frac{Fh}{Fl} \qquad \text{.................................. (3.5)}$$

$$BWnarrowband(\%) = \frac{Fh-Fl}{Fc} \times 100 \qquad \text{.................................. (3.6)}$$

Where Fh is the upper frequency
Fl is the lower frequency
Fc is the centre frequency

3.3.5. Return Loss

Return loss or reflection loss is the signal power's reflection from the insertion of a device in a transmission line. It is expressed as ratio in decibels (dB) relative to the transmitted signal power. The return loss is expressed by [1] as:

$$RL(dB) = 10\, log \frac{Pr}{Pi} \qquad \text{.................................. (3.7)}$$

Where Pi is the supplied power from the souce
Pr is the power reflected back

Let Vi be amplitude of incident wave and Vr be that of reflected wave, then return loss can be written in terms of reflection coefficient ᴦ as in [1]:

$$Rl = -20log|\Gamma| \qquad \text{.................................} (3.8)$$

And the reflection coefficient Γ can be expressed as: $\Gamma = \frac{Vr}{Vi}$

The return loss should be restricted to less than -10 db, so that the antenna can radiate effectively.

3.3.6. VSWR

Voltage Standing Wave Ratio (VSWR) is the wave in the transmission line where distribution of electric parameters like current, voltage or field strength is formed by superposition of two waves of same frequency that propagate in the opposite direction. This voltage standing wave along the line produces a series of nodes and anti-nodes at fixed positions. The VSWR is defined as in [1]:

$$VSWR = \frac{Vmax}{Vmin} = \frac{1+|\Gamma|}{1-|\Gamma|} \qquad \text{.................................} (3.9)$$

VSWR should lie between 1 and 2 for efficient antenna performance.

3.4. Simulation of Rectangular Microstrip Patch Antenna

A rectangular microstrip patch antenna was simulated using CST Microwave Studio Environment 2012. The simulation of any antenna requires to go through three basic steps. Firstly, all the unknown parameters are calculated from the list of known parameters. Then port is created and basic simulation is done to find the S11 parameters. The more simulation is done for further analysis of the patch antenna.

3.4.1. Geometrical Parametrized Design

In the design of the rectangular microstrip patch antenna, the following parameters were considered to be known.

- Resonant Frequency: 1.8GHz (GSM Band)
- Dielectric Constant : 4.3
- Substrate Material: FR4 (Lossy)
- Microstrip Material: Copper (Annealed)
- Speed of Light : 3 x 10^8 m/s

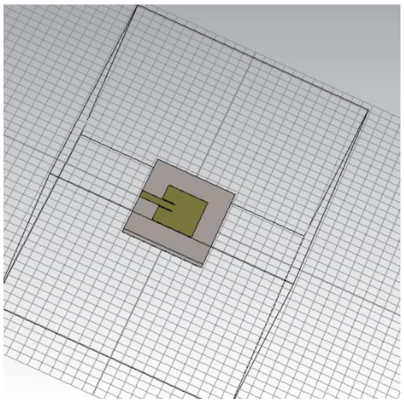


FIGURE 3.2: Rectangular Micro-strip Patch in CST

Quantity	Symbol	Dimension
Length	L	38 mm
Width	W	51 mm
Length of Feedline	Lf	31.5 mm
Width of Feedline	Wf	8.7 mm
Length of Recessed Feed	Fi	12.5 mm
Cut Length	Gpf	1 mm
Height of Substrate	h	4.5 mm
Thickness of Patch	Mt	0.1 mm

TABLE 3.1: Calculated Parameters

- The Length of the Feed-line is taken as 6Wf x (5h+Mt)

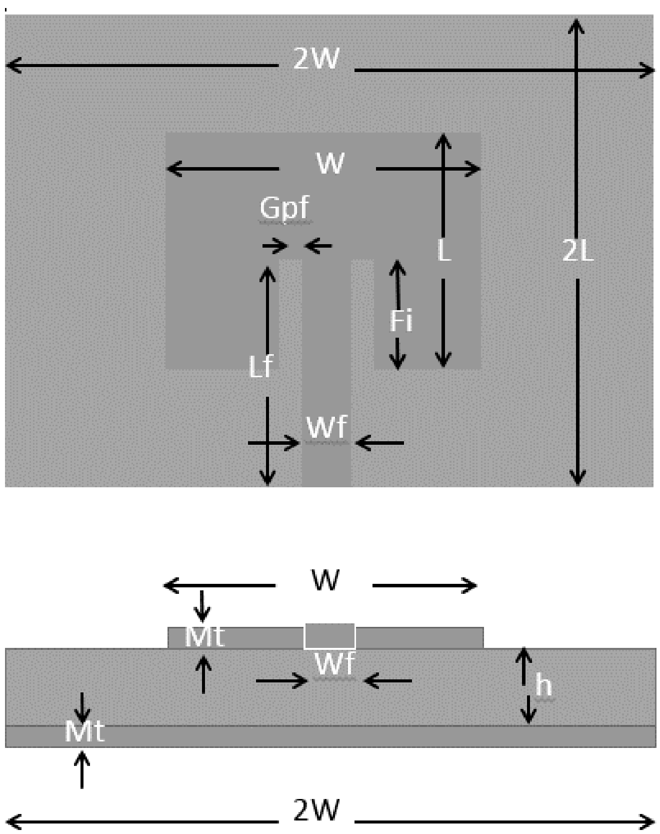


FIGURE 3.3: Top View and Side view of the designed antenna with dimensions

3.4.2. Port Creation and Simulation

The post is fed into the feed-line where a sample decaying input signal is fed. Before simulation of the antenna in CST, some of the properties were set for proper simulation and further analysis.

- Working Plane Properties Settings:
  - Size = 100
  - Raster Width = 10
  - Snap Width = 0.01
- Local Co-ordinate System was Selected
- Waveguide Port was Selected
- No of Modes was limited to 1
- Frequency range is set from Fmin = 0 to Fmax = 2 GHz
- Normalized Line Impedance = 50 Ohms

3.4.3. Analysis and Return Loss Plot

After the simulation all the parameters were analyzed to check for the desired output of the antenna design. As we can see in figure 3.4 the S_{11} curve has been plotted. As we can see the curve just crosses below -10 db at the resonant frequency of 1.808 GHz. Hence even though the antenna is acceptable but a lower S_{11} is expected for better performance. Currently S11 comes to -11.322242 dB .Therefore we have a very low bandwidth of (1.8304 GHz – 1.7842 GHz) = 46.2 MHz as depicted in figure 3.5. in the present design at the Farfield analysis at 1.8 GHz we get Far-Field Power Pattern Main Lobe Magnitude of -6.3dB/sq. m.

The E-plane and H-plane has also been shown. The E-plane is bi-lobed in nature keeping axial angle constant and varying the equatorial angle whereas the H-Plane is circular for a constant equatorial angle and varying axial angle. We can also visualize the 3-D radiation pattern where the areas in red represent directions having higher antenna gain as compared to area having green color. The areas having blue color have no directivity in the direction indicated. The 3-D plot has been further converted into a 2-D plot with varying equatorial and axial plane angles.

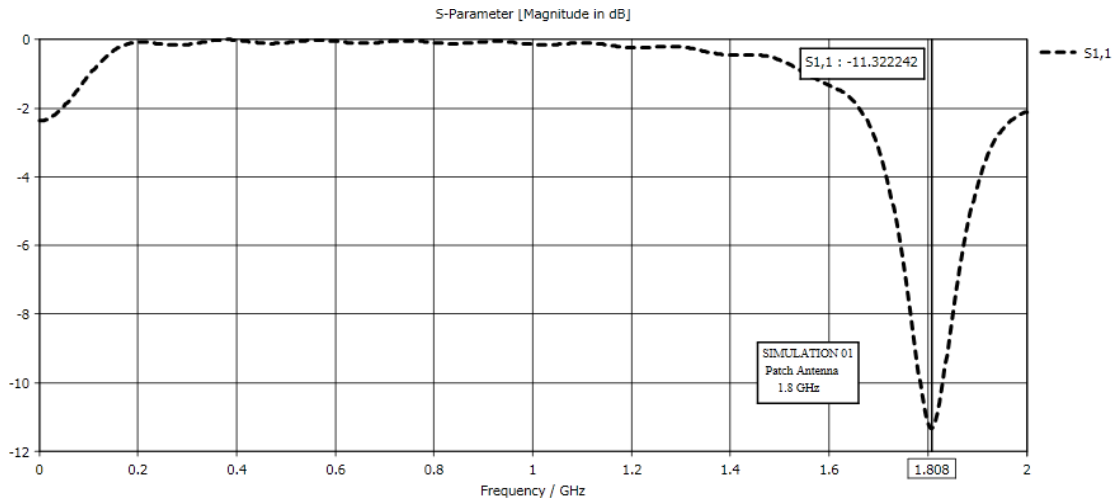


FIGURE 3.4: S-Parameter Curve Showing the Resonant Frequency and corresponding S_{11} value

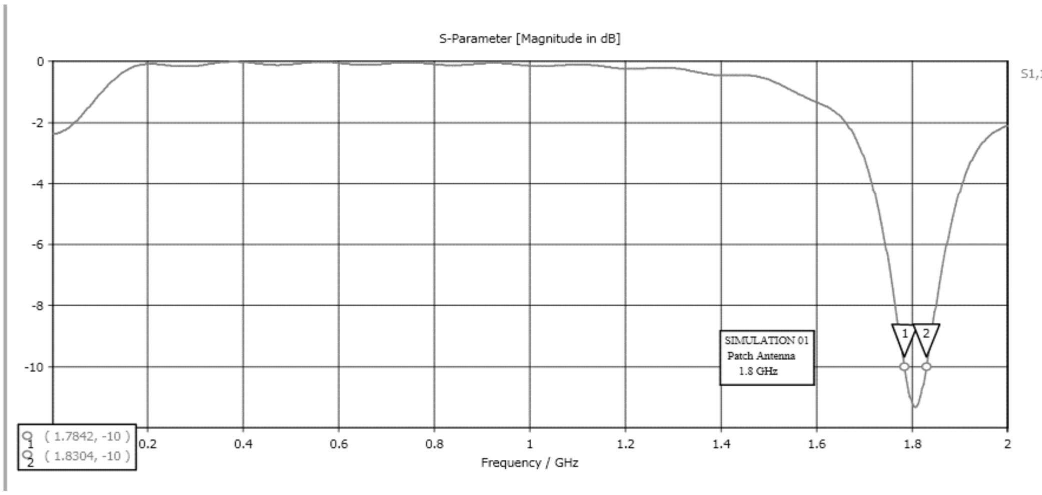


FIGURE 3.5: S-Parameter curve showing the Bandwidth

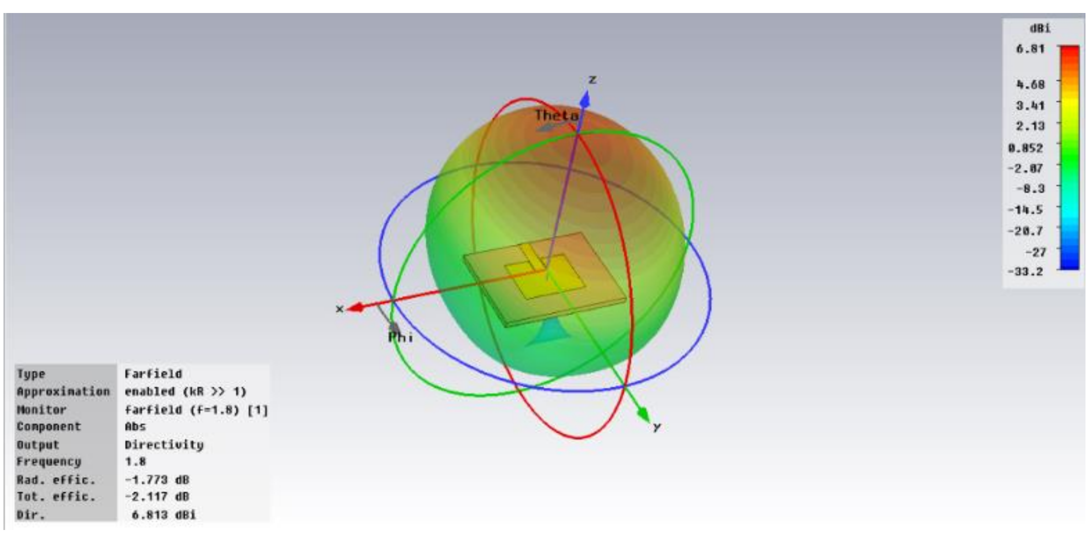


FIGURE 3.6: Radiation Pattern in 3-D plane

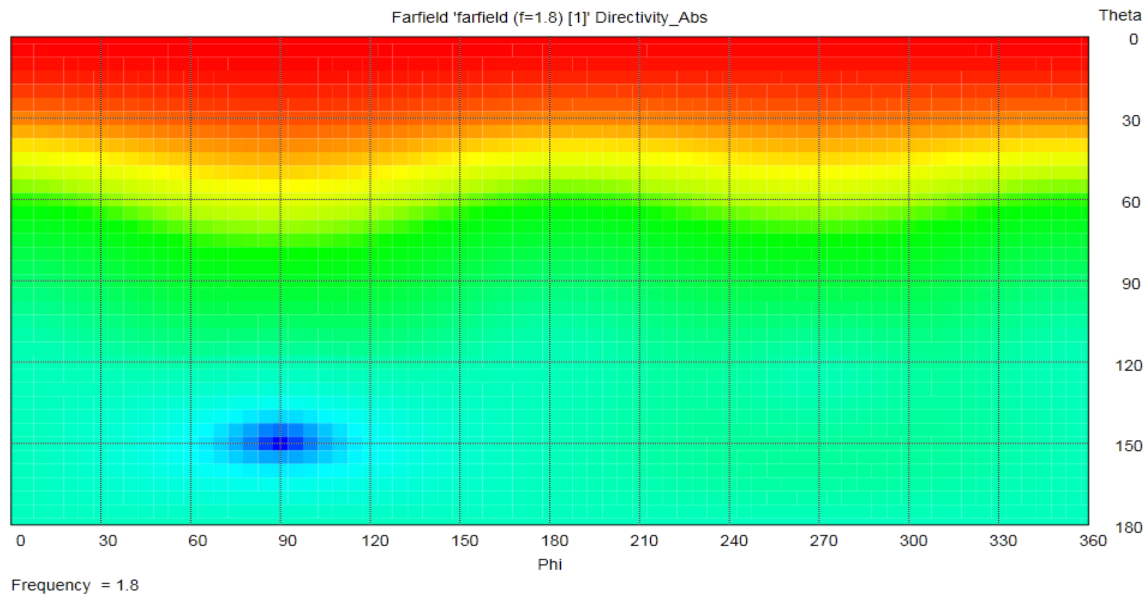


FIGURE 3.7: Radiation Pattern in 2-D plane

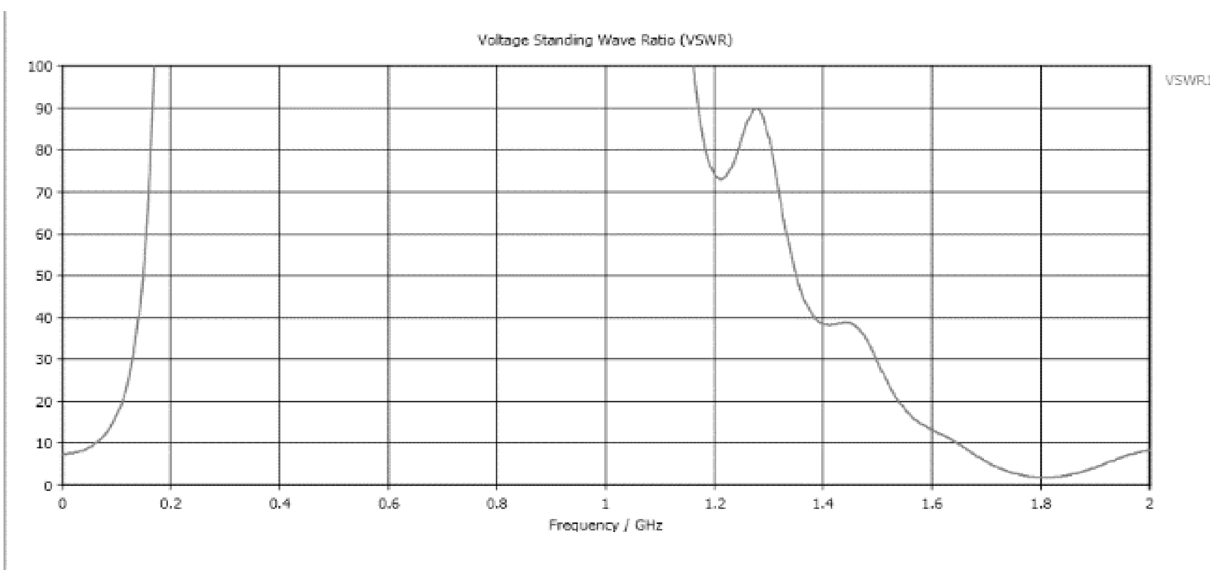


FIGURE 3.8: Voltage Standing Wave Ratio Curve (VSWR)

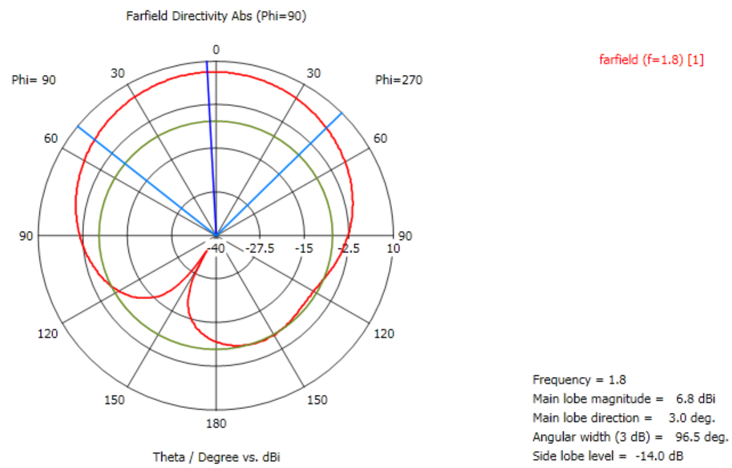


FIGURE 3.9: Farfield Directivity of electric and magnetic field

3.4.4 Conclusion

The above design is not a much optimized design since the VSWR value exceeds the normal value of 100. VSWR is generally expected to lie in between 1 and 2 ideally at the operating frequency. Also in the above experiment, the electric field curve across the equatorial plane is not symmetric. Also the bandwidth is less and is not suited for wireless applications since it does not satisfy Shanon's data rate criterion for GSM applications. The design is just done only learning purposes.

Chapter 4

RECTANGULAR PATCH ANTENNA CALCULATOR GUI

Matlab Guide Environment

Design Architecture for Microstrip Patch Calculator

Execution Steps

Matlab Program

Graphical User Interface

Flowchart for Antenna Design

CHAPTER 4

RECTANGULAR PATCH ANTENNA CALCULATOR GUI

4.1. Matlab Guide Environment

GUIs (Graphical User Interface otherwise called graphical client interfaces or UIs) give control of interacting with programming applications, wiping out the need to take in a particular language or sort orders so as to execute the application.

MATLAB applications are independent MATLAB programs with GUI front end that automate an undertaking or figuring. The GUI ordinarily contains controls like menus, toolbars, catches, and sliders. Numerous MATLAB items like Curve Fitting Toolbox, Signal Processing Toolbox, and Control System Toolbox, incorporate applications with client specific interfaces. You can likewise make your own applications, including their relating GUIs, for others to work upon.

GUIDE (graphical client interface plan environment) gives instruments and helps in planning client interfaces for applications. A graphic plan of the UI can be made using the GUIDE Layout Editor. GUIDE then as a result generates the code in MATLAB for developing the UI, which you can alter to program the conduct of the intended application.

For more control over outline and improvement, you can likewise make MATLAB code characterizing each component. One can include dialog boxes, client interface controls, (for example, push tabs and sliders), and holders, (for example, radio buttons and push buttons).

4.2. Design Architecture for Microstrip Patch Calculator

Here we have worked on to create a GUI for patch antenna calculations. Such an app will help to ease the burden on the designer to repeatedly calculate the antenna parameters using the same standard formula for optimization purposes. The GUI was created using MATLAB R2012b GUIDE. The input parameters set here are frequency in GHz, dielectric constant and thickness in mils (1mil = 0.001 inch = 2.54 mm). The units are standardized in the backend and then using the standard formulae as in Chapter 1 for microstrip patch antenna, the various antenna parameters are calculated.

The output parameters defined with their dimensions are Length (mm), Width (mm), Rad resistance (ohm), efficiency, Gain, Characteristic impedance (ohm). The radiation plot of the E-plane and H-plane patterns plots is displayed. The surface power and total power is calculated using standard equations. Various callback functions and handles have been used to calculate and display the desired results.

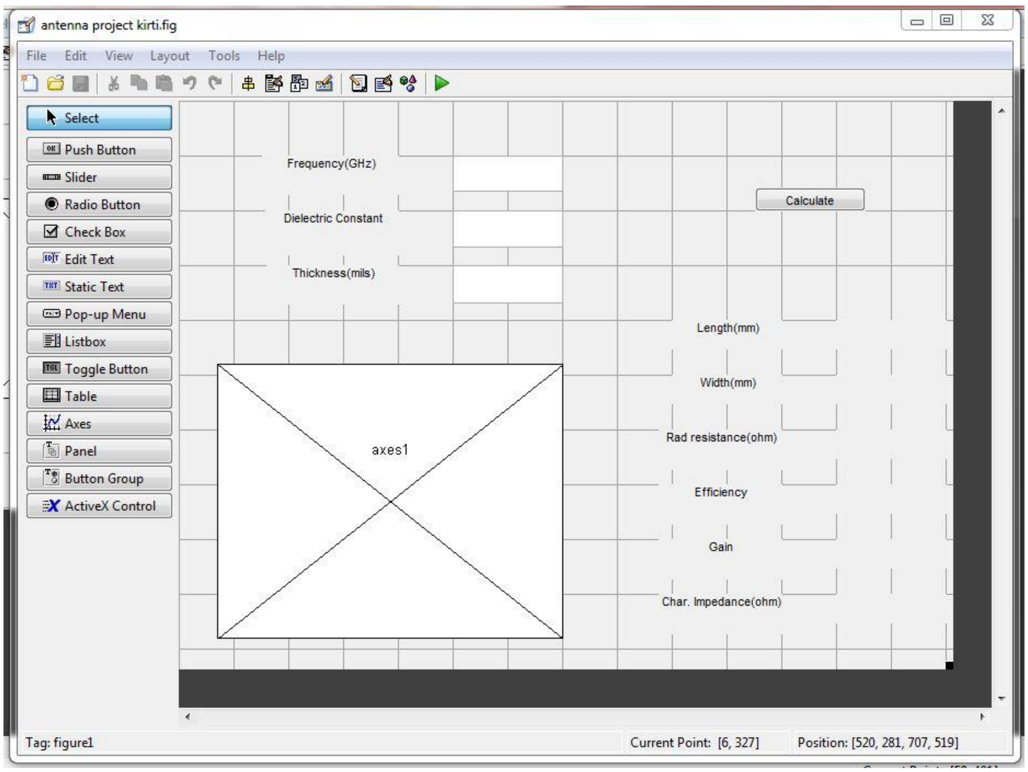


FIGURE 4.1: Design Architecture of Patch Antenna Calculator

4.3. Execution Steps

The Matlab GUIDE is opened and a new *.fig file is created. The GUI is made by using several active elements in the Property Inspector toolbar. The *.m file is generated from the *.fig file execution. At this stage the GUI is ready to run, but actions are not performed. The Callbacks are then integrated in the *.m file that issue the call of action to the active properties on clicking in the GUI. Then one needs to update the Handles data structure for each function with the following line being executed in each updation.

function pushbutton1_Callback(hObject, eventdata, handles)

Next the String is converted to double for input and further processing. Now when we click the pushbutton in the GUI, the corresponding callback function is executed and thus results are displayed accordingly.

4.4. Matlab Program

The program which is generated by MATLAB can be decoded as given below. Moreover we need to enter the required calculative formulas in the proper location in the code to undertake the necessary calculations. The following steps depict the algorithm involved.

1. Initialization Code before begging of any function
2. Opening Function before GUI is visible (Creation of Object)
3. Output returned to command line in variables to further process it to display on UI
4. Create Edit functions and Set Background Color (default color set as white).
5. Set Call back for edit functions i.e. the backend formulations.
6. Execution on push button1 execution i.e. the calculate button to initialize the calculations.
7. Formulation for single variable parameters.
8. Formulation for angle varying parameters.
9. Set output handles for final output display.

4.5. Graphical User Interface

The graphical user interface is made up of three inputs and seven outputs. Six of the outputs are in the form of numerical String while the one output is diagrammatic the calculations have to be done based on the matrix multiplication with the sine and cosine functions. There is an action button in form of the push button which enables the user to check for output after giving input for all values. Double precision is maintained for all calculations. The lines for radiation of electric and magnetic field are in different colours i.e. E-plane in Red and H-plane in Blue. To run the GUI Matlab must be functioning in the backend.

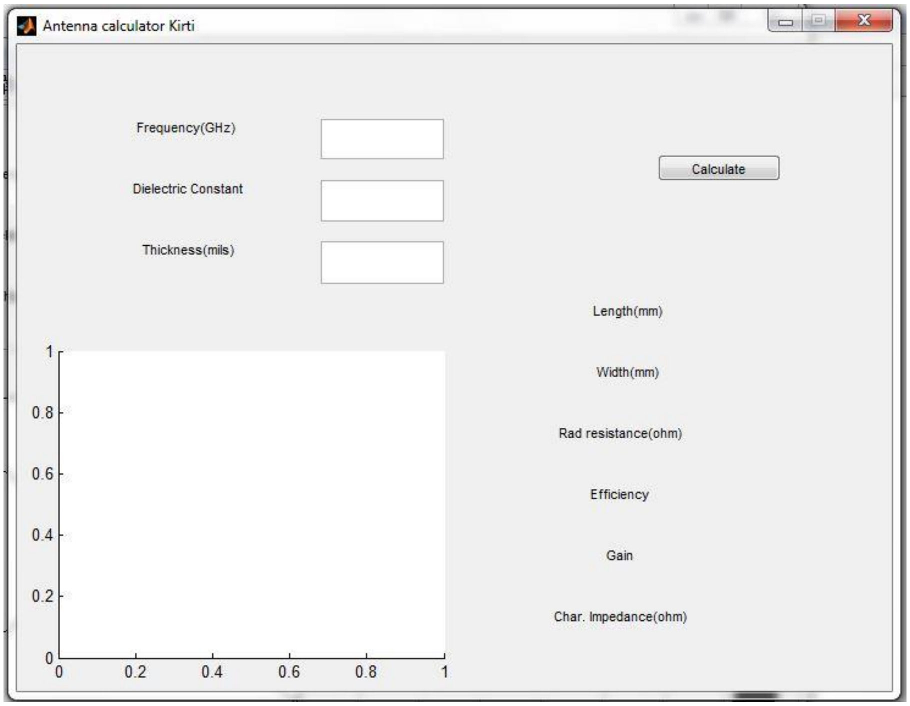


FIGURE 4.2: Blank Window before giving any data input

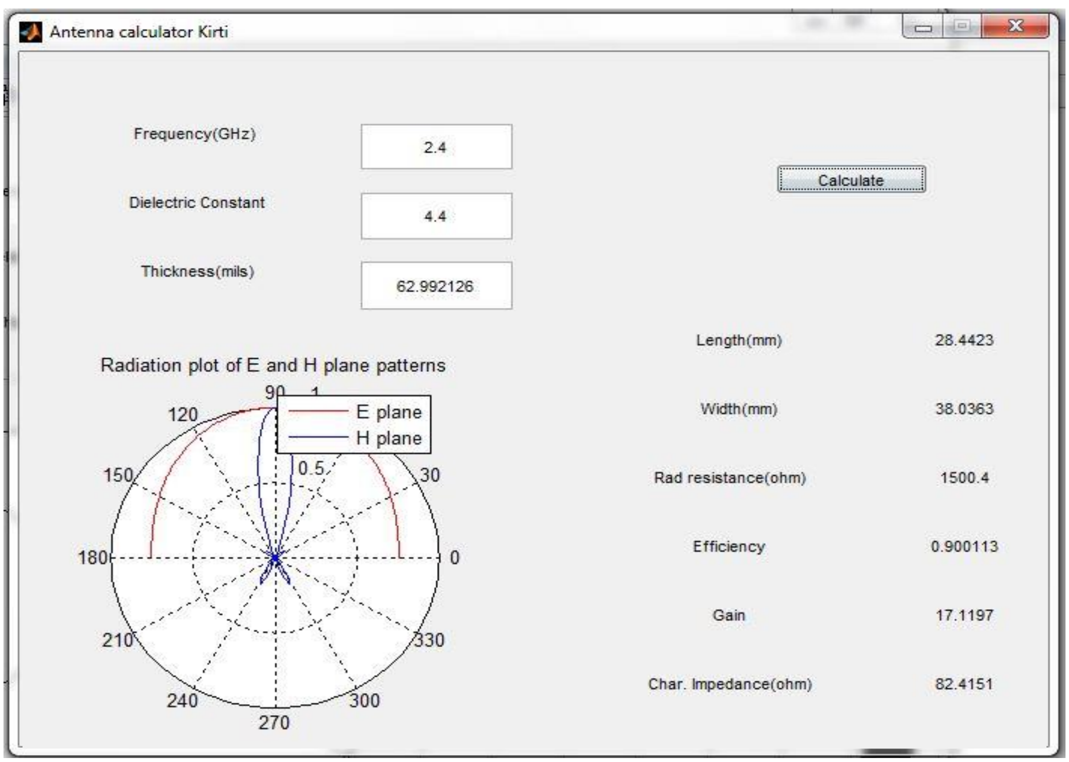


FIGURE 4.3: GUI Window after giving output data

4.6. Flowchart for Antenna Design

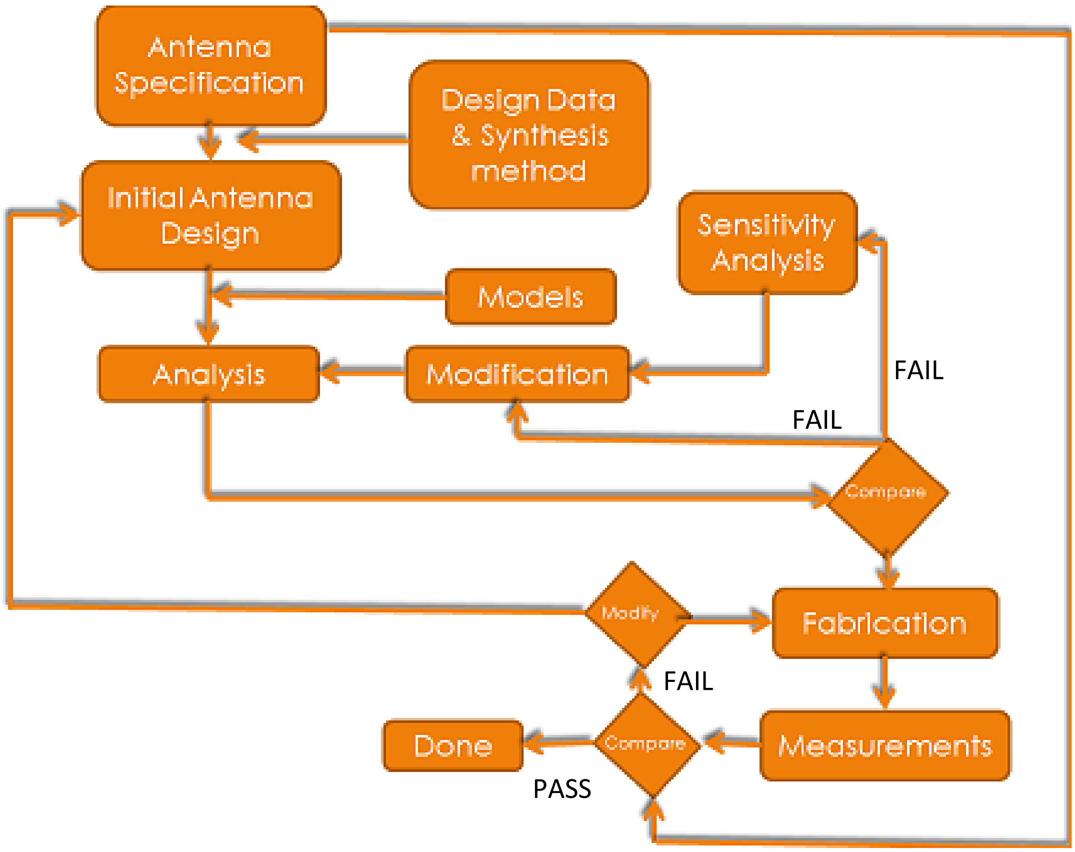


FIGURE 4.4: Generalized flowchart for antenna design and fabrication

In the above figure 4.4, we can see a detailed diagram of how the antenna fabrication process is being followed at an industrial level. The MATLAB Code which has been developed functions in the first part of the flowchart i.e. during the initial design when the design data is available and the synthesis method needs to be chosen.

The program developed can be extended to implement all the compare stages and to fully automate the processes in which simple linear comparison is required. This will ease the designer job further on comparing the designed antenna specifications with the actual fabricated antenna and thus save a lot of time.

Chapter 5

METAMATERIAL BASED MICROSTRIP PATCH ANTENNA

Introduction

Advantages

SRR Structure

Equivalent Circuit Models for SRR

Simulation of Split Ring Resonator

Comparative Study of Metamaterial based antenna

CHAPTER 5

METAMATERIAL BASED MICROSTRIP PATCH ANTENNA

5.1. Introduction

With the arrival of smaller scale framework advancements and nanotechnologies enhanced achievements in various fields of science and innovation. The materials can now be organized for electromagnetic and optical applications which used to remain incomprehensible earlier. Among most likely the best known samples of novel electromagnetic structures are the negative refractive index metamaterials, famously known as left-handed materials [6].

Another result was an amazing scaling down of components miniaturized to an extent like never before. Metamaterials are simulated materials designed to give properties which "may not be promptly accessible in nature". These materials generally pick up their properties from structure instead of compositions, utilizing the consideration of little inhomogeneity to sanction successful macro behavior of negative refractive index (NRM). NRMs are artificial composites, with subwavelength features. These materials were theatrically anticipated in 1968 by Vaselago [7]. With the entry of miniaturized scale fabrication, new conceivable outcomes could be executed for distinctive metamaterials.

The field got to be strongly contemplated by various examination groups. Greatly compelling were original work by Pendry [8]. A further help to the field came when the presence of NRM was tentatively affirmed by Smith, Shelby [9]. By using both intermittent and transitory electromagnetic waves, as proposed by Pendry in 2000 [10] the appropriateness of NRM for lensing much further expanded the enthusiasm for NRM.

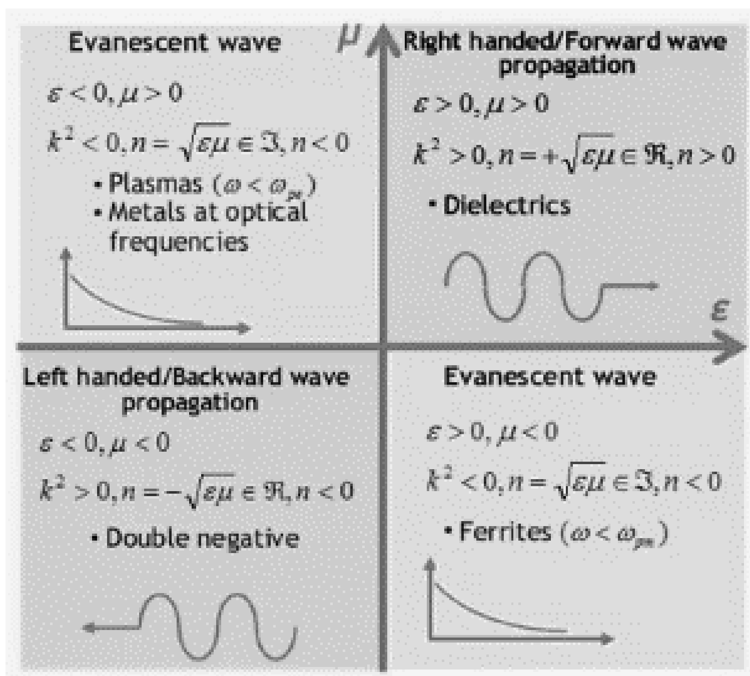


FIGURE 5.1: Metamaterial quadrant diagram

5.2 Advantages

Negative Refractive Index Metamaterials (NRM) are the most commonly used metamaterial configuration used currently in antenna design. Some of the advantages of metamaterials are:

- Metamaterials used in antennas to increase performance of miniaturized (electrically small) antenna systems
- Structure is made such that most of the wave is re-radiated after reflections.
- Used in Wireless Communication, Space Communications, GPS, Satellites, Space Vehicle Navigation, Airplanes
- Configurations Used: Dual Positive Substrate (DPS) , Dual Negative Substrate (DNG), Epsilon Negative Substrate (ENG), Mue Negative substrate (MNG)
- Negative Permittivity due to wire array (electric field negation)
- Negative Permeability due to SRR Array (magnetic field negation)
- Left Handed Material: Split Ring resonator (SRR)/ Complementary SRR
- Reduction of mutual coupling between elements in an antenna array
- Behave as high pass filter with phase advance
- Bandwidth Improvement
- Gain Miniaturization
- Higher Directivity

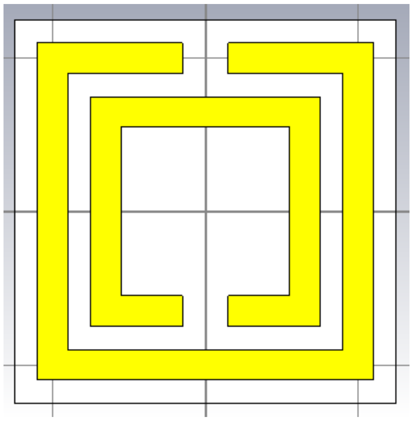
5.3. SRR Structure

In early 1950s, Special ring like resonating structures were made and tested for artificial materials in microwave. As described in [11] Split Ring Resonator (SRR) as shown in figure 5.2 is a structure having high conductivity. Here capacitance between the structures balances the inductance. It is shown in the equivalent circuit diagram as shown in figure 5.4. When a time-varying magnetic field is applied in perpendicular to the rings and a time-varying electric field is applied across the metallic strip produces the negative permeability and negative permittivity effect respectively. The SRR can come in various structures and implementations for giving negative permeability.

The negative permeability can be defined as

$$\boldsymbol{\mu}_{eff} = 1 - \left(\frac{\left(\frac{\pi r^2}{a}\right)}{1 + \frac{2\sigma i}{wr\mu o} + \frac{3d}{\pi^2 \mu w^2 \epsilon o \epsilon r^2}} \right)$$

Where, a – unit cell length σ – electrical conductance



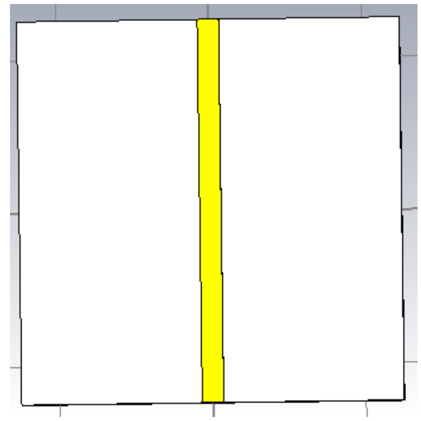


FIGURE 5.2: Front View (SRR)

FIGURE 5.3: Rear View (Metallic Strip)

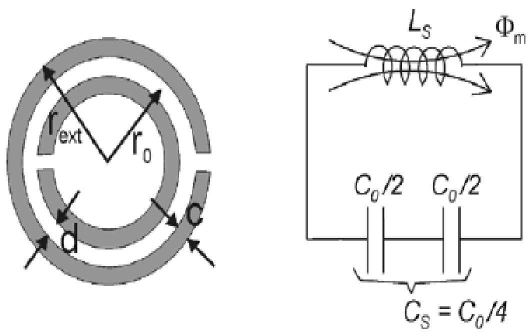


FIGURE 5.4: Equivalent Circuit of SRR

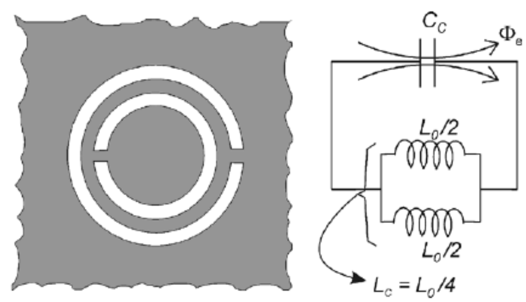


FIGURE 5.5: Equivalent Circuit of CSRR

CSRR are complementary SRR where the metallic layer is replaced by the substrate and vice versa. The show a dual circuit property to each other. The description is pretty clear from both the figures 5.4 and 5.5.

5.4. Equivalent Circuit Models of SRR

The four types of SRR variants are mentioned below even though numerous structures can be formed. Though they are equivalent to the standard SRR structure, still there is some type of phase difference with the individual use.

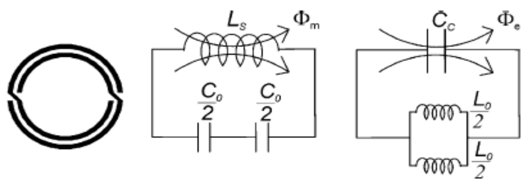


FIGURE 5.6: Non-bian-isotropic Split Ring Resonator (NB-SRR)

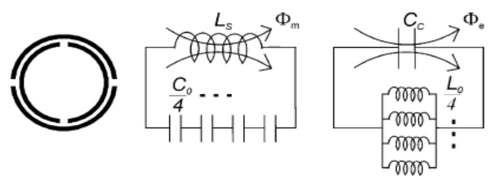


FIGURE 5.7: Double Slit Split Ring Resonator (D-SRR)

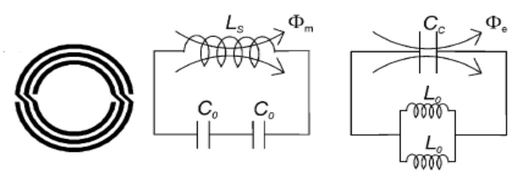


FIGURE 5.8: Spiral Resonator (SR)

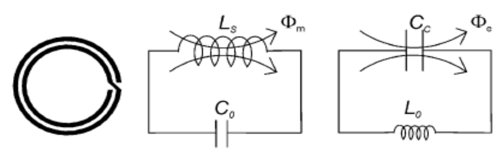


FIGURE 5.9: Double Spiral Resonator (DSR)

The topologies that are available are Non-bian-isotropic Split Ring Resonator (NB-SRR), Double Slit Split Ring Resonator (D-SRR), Spiral Resonator (SR), Double Spiral Resonator (DSR). The variation in properties that exist are such as NB-SRR has resonant frequency equivalent to SRR but D-SRR has resonant frequency twice that of SRR. On the other hand SR & DSR allow reduction in resonant frequency as compared to SRR.

5.5. Simulation of Split Ring Resonator

A single unit Cell of the Split Ring Resonator can be simulated to operate at a particular frequency i.e. in the operating frequency where the permeability becomes negative. Thus boundary conditions need to be solved using Eigen functions. In the simulation of Split Ring Resonator, we need to set the boundary conditions. So for that the magnetic boundaries is perpendicular to the SRR plane and the electric field port is inserted the metallic wire. The presented designed SRR resonates at 9.75 GHz but it was calculated to resonate at 10.25 GHz. The input signals are given to all six sides. And checked for resonant frequencies with the intersection point of S12 and S21.

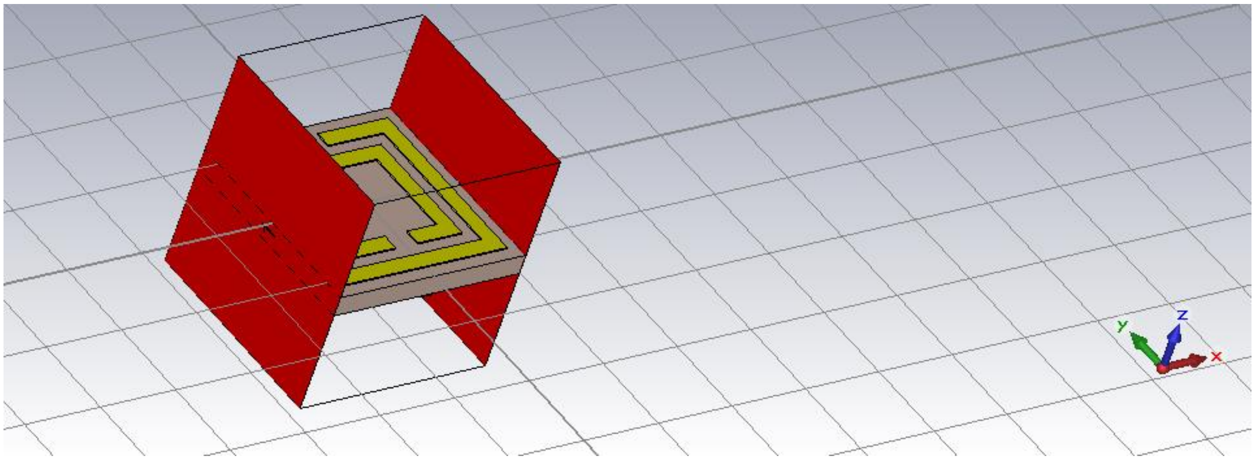


FIGURE 5.10: Port Simulation in SRR Unit Cell

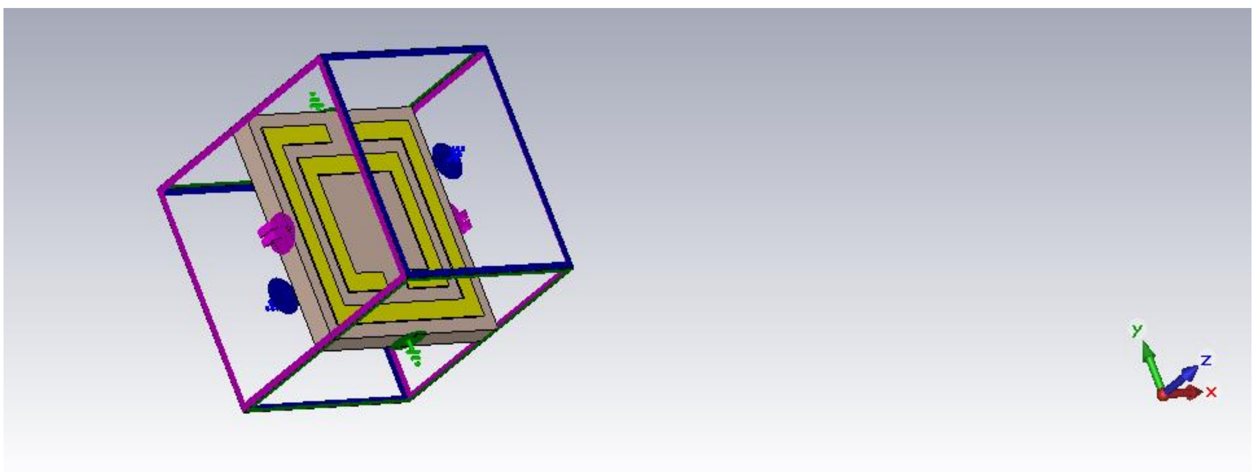


FIGURE 5.11: Magnetic Field and Electric Field boundary Condition

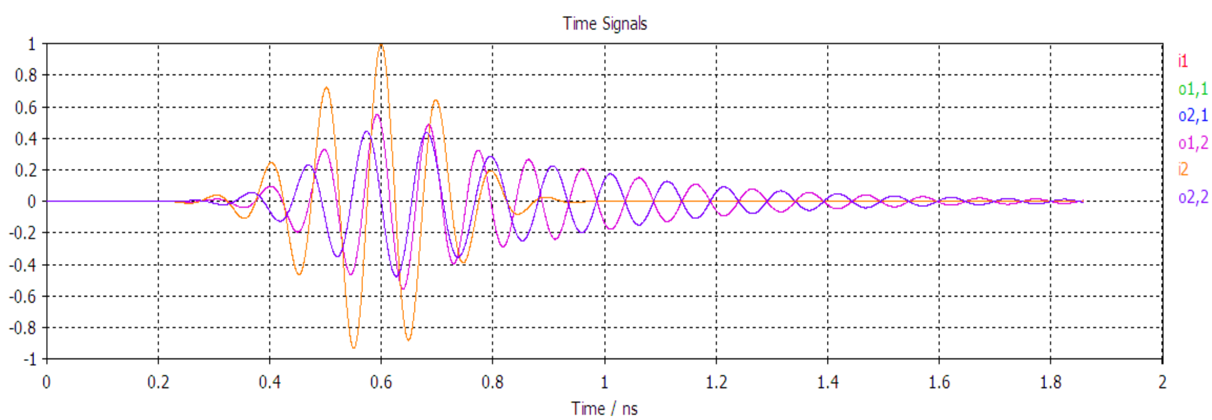


FIGURE 5.12: Input Port Signals

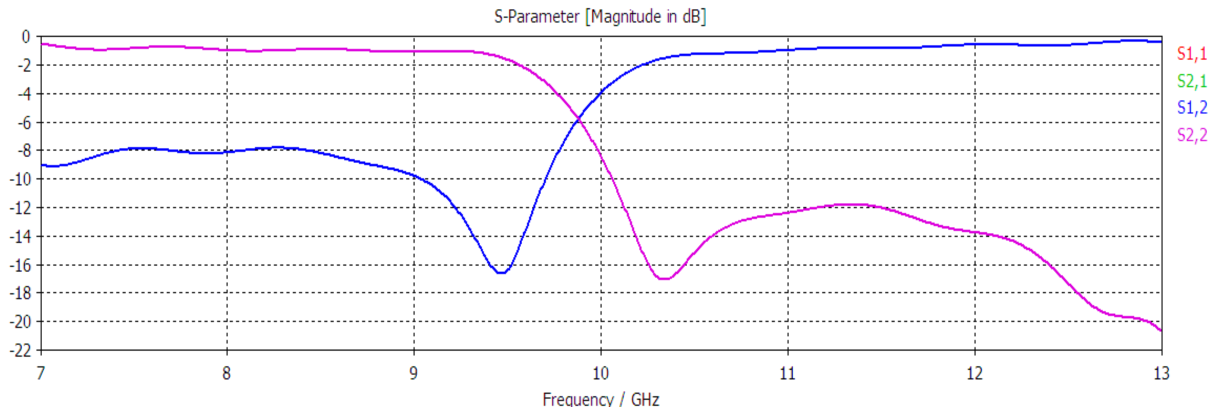


FIGURE 5.13: Resonant frequency of 9.75 GHz in SRR Unit Cell

5.6. Comparative Study of Metamaterial based antenna

Here we have presented a comparative analysis of the improvement in metamaterial based antennas. The three configurations have been considered that is the interdigital structure introduced in one arm of the patch, a defected ground structure and an EBG Structure.

5.6.1. Inter Digital Structure

In this antenna inter digit structures were introduced in one arm of the antenna. It was found that for the same frequency metamaterial antenna require 65.49% less space than conventional antennas. Also there is bandwidth improvement for the same dimension.

Property	Conventional Antenna	Metamaterial Loaded Antenna
Band 1	1.207 – 1.239 GHz	2.48 – 3.05 GHz
Band 2	1.164 – 1.216 GHz	2.516 – 3.608 GHz
Size at 1.2 GHz	100%	34.51%

TABLE 5.1: Comparative Analysis

Antenna Parameter	Dimensions
L1	23
L2	17
W1	22
W2	10
S	0.29
S1	0.2
S2	11.3
S3	1.5
S4	2
Wf	3
G1	21
Ɛr	4.4
h	1.6

TABLE 5.2: Antenna Dimensions

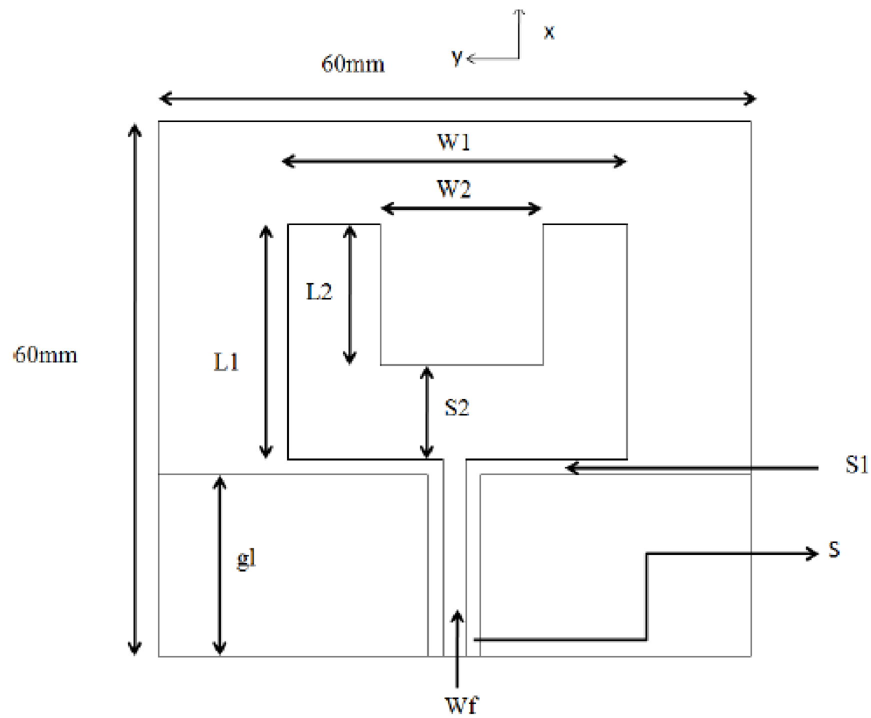


FIGURE 5.14: Conventional Microstrip Patch Antenna

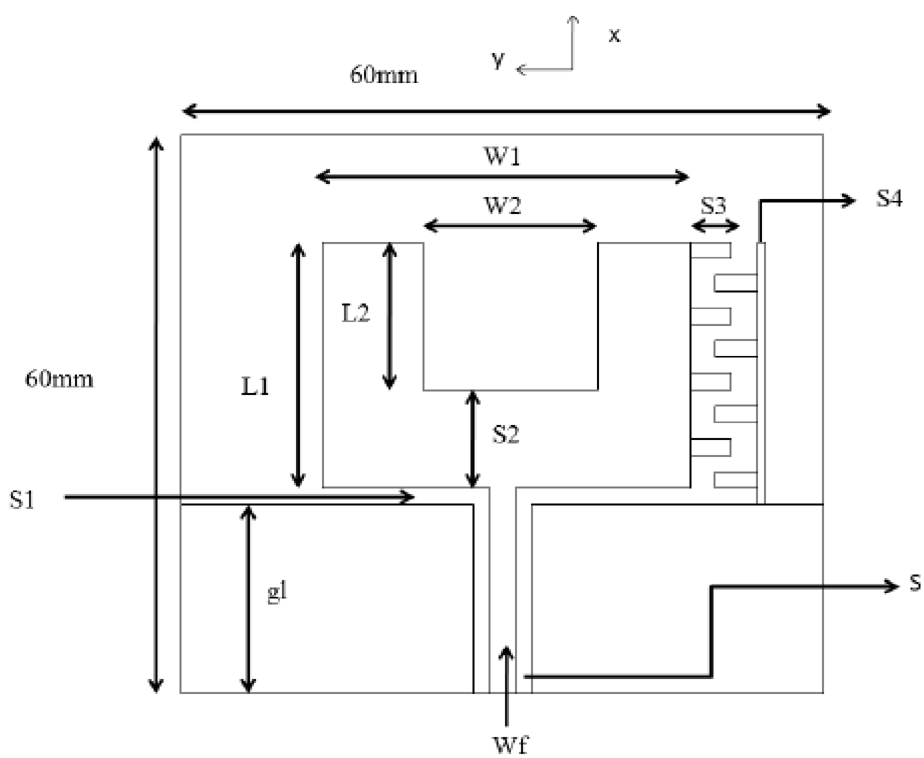


FIGURE 5.15: Microstrip Patch Antenna with interdigital structures in one arm

5.6.2. Defected Ground Structure (DGS)

In such structures the ground plane consists of some variety of spiral resonator etched from the ground plane. The following table alongside shows the dimension of the antenna. Two antennas are studied here one with DGS and one having conventional ground plane structure. The thickness of the substrate is 0.035 mm and the height is 0.7 mm.

Antenna Parameter	Dimensions (in mm)
Ws	36
Ls	36
g1	2.24
r1	6
r2	5
r3	4

TABLE 5.3: DGS Dimensions

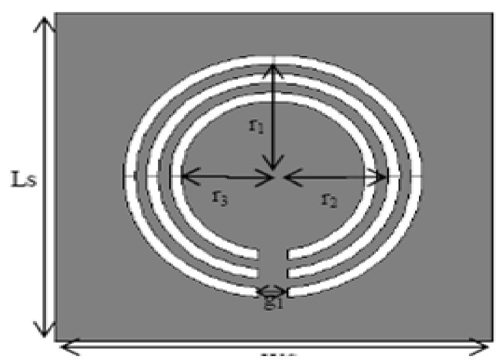


FIGURE 5.16: Defected Ground Structure

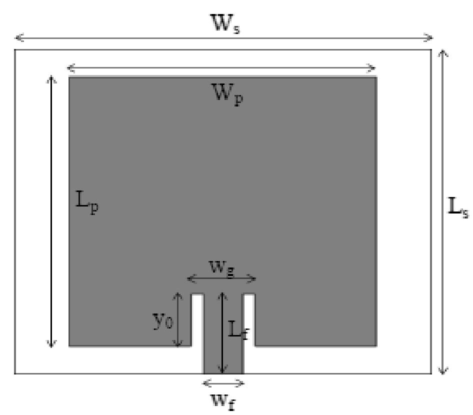


FIGURE 5.17: Antenna Top View

Property	Conventional	Metamaterial Loaded
Ws	44	19
Ls	39.65	17.55
Wp	39	14
Lp	34	14.55
Yo	11	2.8
Lf	13.825	4.3
Wf	1.78	1.8
Wg	5.8	2.9
S11	-22.99 db	-37.22 db
BW	14.2	25.4
Area	39 x 34	14 x 14.55
Directivity (dbi)	5.181	5.93
Resonant Frequency	2.478 GHz	2.285 GHz

TABLE 5.4: Comparative Analysis of the DGS and Conventional Antenna

5.6.3. CSRR Loaded Patch Antenna

The CSRR Cell is first made for a particular frequency and then an array is made to operate at that particular frequency so that together it can show an improvement in antenna characteristics owing to its metamaterial property.

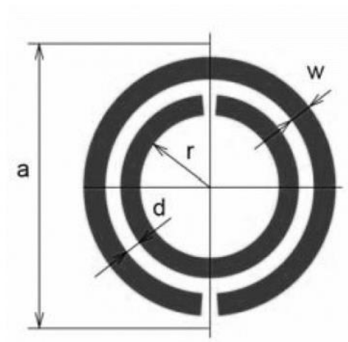


FIGURE 5.18: CSRR Unit Cell

Unit Cell	r1	8
	r2	5
	c	2
	d	1
Upper Cell	l	54.775
	w	70
	Lf	5.009
	Wf	9.9
CSRR Array	Length	86
	Breadth	50

TABLE 5.5: Antenna Dimensions

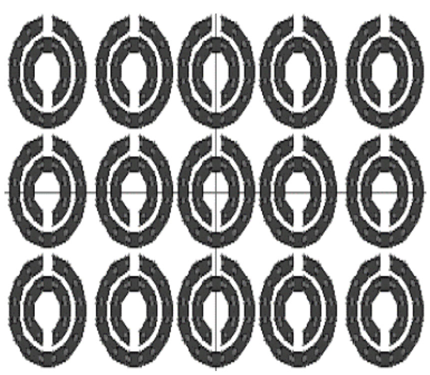


FIGURE 5.19: CSRR Array in ground plane

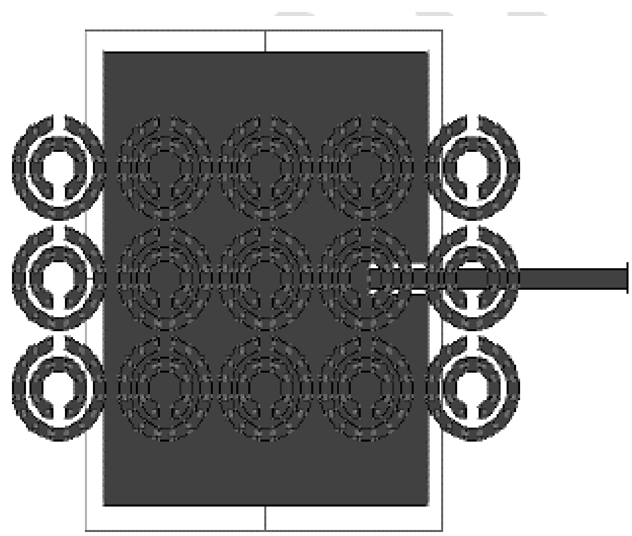


FIGURE 5.20: Antenna Structure

Chapter 6

CONCLUSION AND FUTURE SCOPE

In this thesis work, the focus was mostly on study of methods that help in optimization of the antenna designs. A MATLAB based GUI was developed for easy to use User Interface System for calculations of basic parameters of microstrip patch antenna. The GUI will be a useful tool in visualizing the antenna parameters without involving the complicated equations, since that part will be handled in the backend.

A detailed study was done on the comparisons between conventional and metamaterial based antenna. The comparisons were comprehensive and consisted of study of the antenna designs in same frequencies and changing dimensions. All the simulations were all carried out in CST Microwave Studio Software. The simulation and analysis shows very close results to the actual conditions and the antenna can be optimized there saving both money and time. Due to lack of fabrication facilities the antenna could not be actually made and tested in Vector Network Analyzers (VNA) for actual performance.

The metamaterial antenna in the SRR structure was studied in detail. The equivalent circuit were analyzed and it was found that for various applications different structures can be implemented for different applications. So highly optimized antennas can be designed.

In future more analysis could be done on different type of antenna and how they can be better than other antennas that are conventional in nature. The aim must be to find the suitable design for particular application so that there is no spurious radiation or bandwidth wastage. A catalog for such application based antennas can be made which can reduce time-to-market in various portable electronics devices for various applications.

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